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Phase Scan Signature Matching for Linac Tuning

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Abstract

A relatively simple method for linac tuning has been devised and tested on the Alvarez linac. Tank phase is varied over 360 degrees while the phase of signals from strip-line detectors is measured. Reference phase is taken from the master oscillator for the linac. Theoretical curves of beam phase versus tank phase are matched to the measured curves to determine the tank field amplitude and phase, and the input and output betas of the tanks. Preliminary experiments on tanks 4-7 of the Alvarez linac demonstrate the feasibility of the technique.

I. Introduction

The idea of comparing broad-phase-scan signatures with theory to determine tank field amplitude, phase, and input energy was suggested a few years ago and was first described on pages 15 and 16 of reference 1. References 2 and 3 are later papers which also allude to the idea. In some of the early concepts, as tank phase is varied over a wide range, beam phase is monitored at two points along a free drift region beyond the tank being tuned. The beam phases are used to calculate beam energy changes through a tank. From theorétical analyses presented in reference 1, it was found that characteristic features of the curves varied in a well-defined fashion as the tank amplitude and input energy changed. The proper tank phase could be set to calculated values along the abscissa of the phase-scan curves. Originally, the technique was suggested as a means of coarse tuning the linac, followed by fine tuning with the classical delta-t procedure (references 1,2). Our recent measurements suggest that the signature matching technique alone may be sufficiently accurate to set tank phase and amplitude to their final values.

The method described in this report represents a slight variation from the method described in references 1-3. In its present embodiment, the beam phase is measured at only one position beyond the tank being tuned. Data are presented in raw form rather than converting to energy values. The phase-scan-signature method circumvents a potential problem with the classical delta-t procedure. Namely, errors can occur in the delta-t procedure if the input energy to a tank differs from design. This potential source of error was discussed in reference 4 in connection with the linac upgrade at Fermilab.

II. Experimental Procedures

Beam induced voltages containing beam phase information are monitored on strip-line detectors which are part of the beam-position-monitoring system. For each tank being examined, the downstream tanks are turned off and the beam drifts freely through these tanks. The beam is monitored at a position either immediately out of the tank being examined or one tank downstream. The phase of the strip-line signals is measured using an I/Q phase detector, first suggested to us by Olin Vandyck at the Los Alamos National Laboratory. The detector output is periodic, repeating every 2π radians. The beam phase can vary over a range much greater than 2π radians. The data analysis software keeps track of the number of 2π increments which occur in the phase scans. The software can also shift the curves or sections of the curves along the tank phase coordinate.

Tank phase is currently adjusted using a pair of electronic phase shifters placed in series with the master oscillator line for each tank. The control voltages for the electronic phase shifters are converted to tank phase readings through the controls software. The tank phase reading represents the phase of the drive power for the tank. Since the beam can induce fields in the tank, the tank phase reading provides an accurate indication of the phase of the tank fields only if the feedback system holds the tank phase reasonably constant as the beam passes through the tank. The beam intensity during our experiments was set to a low level to insure that this is the case. For the Linac Upgrade, and for subsequent experiments on the Alvarez linac, we plan to monitor the phase of the tank fields directly, using phase detectors connected to field monitors in the tanks. This procedure eliminates the need to monitor feedback system regulation and facilitates measurements at high beam intensity.

Initially, the rf power into the tank being examined is turned off and the beam phase is measured. All subsequent phase readings for a particular tank are subtracted from this zero-power phase reading. The theoretical phases are similarly referenced to the zero-power phase. In curve matching experimental curves to theoretical curves, the beam phase coordinates of the curves do not need to be shifted, since they are referenced to the same zero-power beam phase coordinate. The tank phase coordinates do need to be shifted to match curves (curves shifted horizontally), since absolute tank phase is not known.

Tank phase should be varied over 360 degrees for at least two reasons. First of all, more complete comparisons between theory and experiment can be made. Secondly, this procedure allows us to check that the beam phase at

360 degrees equals the phase at 0 degrees. If the two beam phases are equal, we have some degree of confidence that our calibrations are accurate and that increments of 360 degrees have been properly tracked by the software. Many of the tanks in our linac experiments could not quite cover a full 360 degrees, but the coverage was adequate to assess calibration accuracy and software performance.

III. Phase Scan Signatures

Phase scans for tanks 4-7 of the Alvarez linac are presented in figures 1-4, along with theoretical curves (solid lines, or dashed lines). In the subtitles of the figures, the quantity, dwa, represents the deviation in beta from design. The quantity, E, is the electric field value, relative to design. The electric field and tank input beta are adjusted until reasonable curve matches are obtained. The experimental curves have been shifted horizontally to best match the theoretical curves. No vertical movement of either curve has been made, as mentioned above. Since the curve matching process has been done manually the curve fits are not optimized from the standpoint of chi-squared minimization.

Figures 3 b-d show a typical sequence of theoretical curves in which the tank input beta differs from design by -0.5%, 0%, and +0.5%, respectively. For each figure, theoretical curves are shown for tank field equal to design value (middle curve), 5% high (upper curve), and 5% low (lower curve). The variation in curve signatures shows that differences in input beta of +-0.5% and tank electric field of +-5% can be easily identified from the curve signatures. For tank 6, the theoretical curves show a poor match with the measurements when the input beta used in the theory is higher than the design value. A much better match occurs when the input beta is lower than or approximately equal to the design value. A good match for tank 6 occurs when the input beta is 0.999 times design, and the electric field is about 2% higher than design. The comparison between theory and experiment when a good match is obtained is shown in figure 3a.

Once the curves have been matched, the phase setting for the synchronous particle will be at the zero of the abscissa. This would normally be the design phase setting if the input beta and tank field were also set to design values. For tank 6 the actual phase setting is 26.5 degrees from the zero on the curve. This value represents the largest deviation from design phase we found among tanks 4-7. Fortunately, the rf bucket is large enough and the beam bunch small enough that this large deviation from design phase does not diminish beam quality significantly, as demonstrated in computer simulations using the LAMA computer code.

In regions to the right of the peaks of the curves, the beam phase readings change very rapidly with tank phase. The signals become noisy and impossible to track accurately over a small range of tank phase to the right of the peaks. In these regions, the tank phase is approaching the right separatrix of the phase space trajectory curves. The beam bunches entering a tank in this region of phase space tend to be strongly perturbed. We have observed the beam intensity drop at the end of the accelerator in this range of tank phase, indicative of beam spill.

We also discovered in the experiments that the beam phase, measured when the tank phase was set to zero degrees, did not equal the beam phase when the tank phase approached a setting of 360 degrees. This discrepency indicated a problem in the tank phase calibration. The large deviation from theory at the end of the curves for tanks 5 and 7, and the discontinuities in the left portions of curves for tanks 4 and 6 result from this problem (keep in mind that a constant has been added to the experimental tank phases during curve matching so that the values no longer start at 0 and go to 360 degrees). The sections of the curves up to the discontinuities for tanks 4 and 6 were moved, during data analysis, from the right portion of the curves to the left portions of the curves. This editing was done partially to see how well the tail (360 degree tank phase setting) of the curves matched the head (0 degree tank phase setting). No editing of this kind was performed on data for tanks 5 and 7.

The tank phase calibration was subsequently checked. Larry Allen provided the raw data allowing us to calculate tank 6 phase relative to tank 5 phase as a function of the phase adjustment for tank 6. Actual phase in tank 6 was determined from analysis of the inter-tank mixer IF signal. Figure 5 shows the comparison of tank 6 phase setting with inter-tank phase reading. Superimposed on the experimental points is the curve that would occur if the two parameters were equal, except for a relative shift of the curves along the horizontal axis.

We find in figure 5 that the phase calibration appears to be accurate to better than about +-5 degrees over about two-thirds of the adjustment range. The error in tank phase at the extreme end of the phase adjustment range is about 30 degrees. This error near the extreme end of the phase adjustment range then explains the large deviations from theory in the curves at the high end of the tank phase adjustment observed in the figures. In subsequent experiments we plan to monitor the tank phase directly, using one of the I/Q phase detectors which we currently use to monitor beam phase. This procedure will eliminate the above source of error.

Table I presents a summary of the calculated tank parameters based upon the curve matches. We have avoided matching the curves at the high end of tank phase settings where the tank phase readings are inaccurate, as described above. Table I shows that most of the tanks are fairly close to their design points, with the exception of tank 6. For tank 6 the input beta is about right, but the phase deviates from design by 26.5 degrees. Primarily because of this large phase deviation, the output beta for tank 6 is 0.7% high (energy is 1.7% high). Of importance to the Linac Upgrade is the observation that the output beta for tank 5 is low by about 0.2% or the output energy is low by 0.48%, compared to design values. The input energy for the Linac Upgrade will therefore be 115.98 MeV instead of 116.54 MeV if tanks 1-5 of the Alvarez linac are not re-tuned.

A consistency check of the curve matches can be made by calculating the output beta of each tank using the actual electric field, phase setting, and input beta indicated by the curve matching. The output beta of a given tank should then equal the input beta found for the next tank. It can be seen that output beta of each tank very nearly equals the input beta of its next nearest neighbor for each tank examined, lending considerable credibility to the results.

IV. Conclusions

These measurements have shown that phase-scan curve matching is a feasible technique for determining the field amplitude, phase, and input beta for linac tanks. The technique could be used to tune modules of the Linac Upgrade when it is ready for commissioning. To implement the procedure on the Linac Upgrade, we would recommend that a target phase-scan curve, generated from theory, be displayed on a CRT screen for each module of the Linac Upgrade. The experimental phase scan curves would be superimposed on the screen to facilitate immediate comparisons with the design curves. Module amplitude and input beta would be adjusted until the measured curves matched the theoretical target curves. Input beta would be varied by adjusting the phase of upstream modules. The phase of the module would then be set to a calculated position along the abscissa of the phase-scan curve.

Table I. *Tank parameters calculated from curve matching.*

Tank #	4	5	6	7
Deviation from Design				
1. *Tank Phase (Deg.)*	8.3	-4.7	26.5	7.7
2. *Input Beta (fraction)*	1.000	0.999	0.998	1.005
3. *Output Beta*	0.999	0.998	1.007	0.998
4. *Field Amplitude*	.98	0.94	1.03	0.95

V. Acknowledgments

We would like to thank Larry Allen for skillfully operating the linac during these experiments. We would also like to thank Elliot McCrory for willing and helpful assistance during these experiments, and for the use of his bpm system and data acquisition routines. We have also benefited from helpful discussions with Peter Ostroumov, and Olin Vandyck.

References

1. T. L. Owens, "Phase and Amplitude Tuning Procedures for the Fermilab Linac," Fermilab Report TM-1713, Jan., 1991.

2. T. L. Owens and E. S. McCrory, "The Delta-T Tuneup Procedure for the Fermilab Linac Upgrade," in *Conference Record of the 1991 IEEE Particle Accelerator Conference,*, May 6-9, 1991, pp. 3064-3066.

3. P. N. Ostroumov, et. al. , "Proton Beam Acceleration up to 160 MeV at the Moscow Meson Factory Linac," ibid., pp. 3067-3069.

4. T. L. Owens, "The Delta-T Tuning Procedure for the Fermilab Linac Upgrade," Fermilab Linac Upgrade Document LU-177, April, 1991 (Attn: L. Lopez, mail station 307).

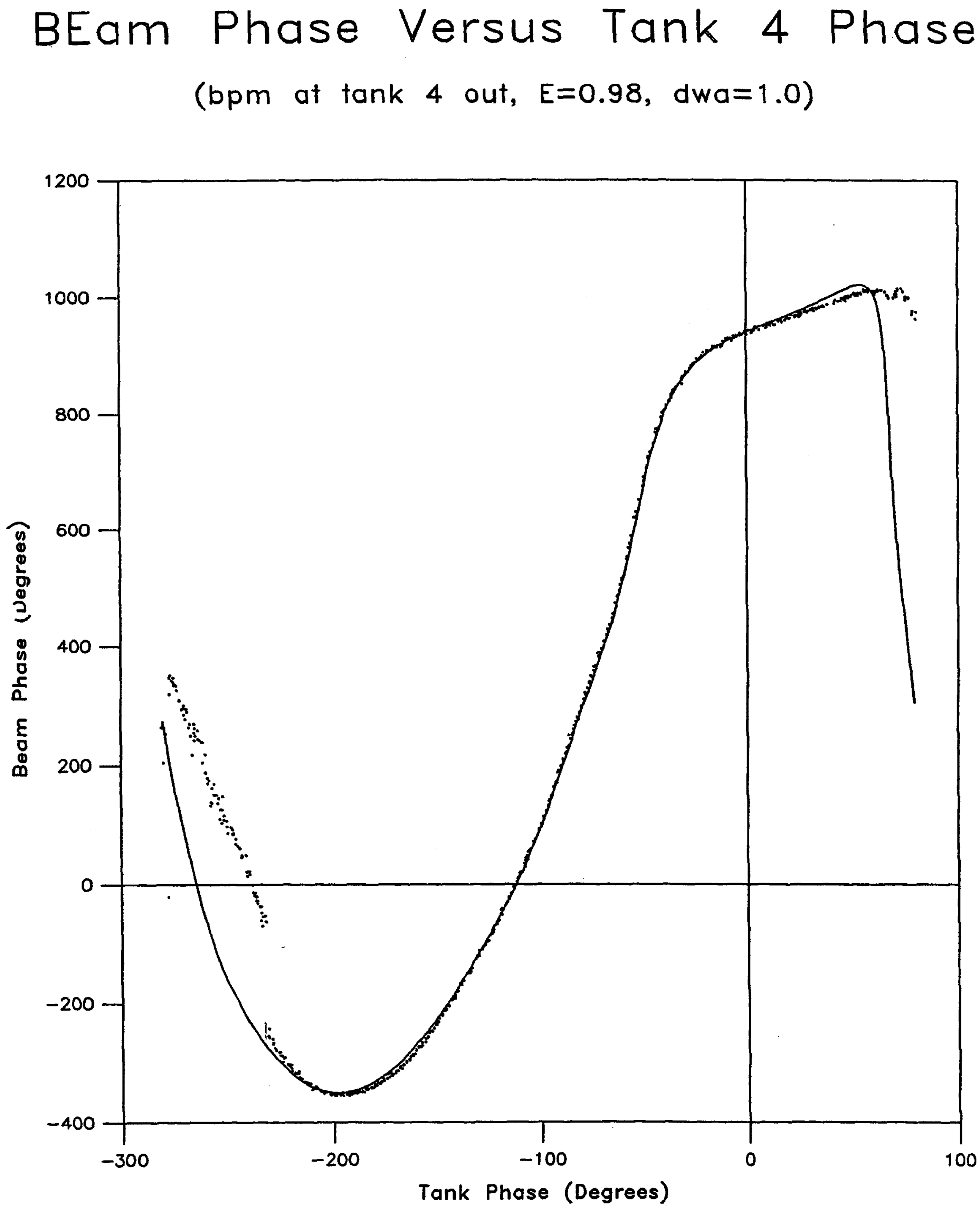
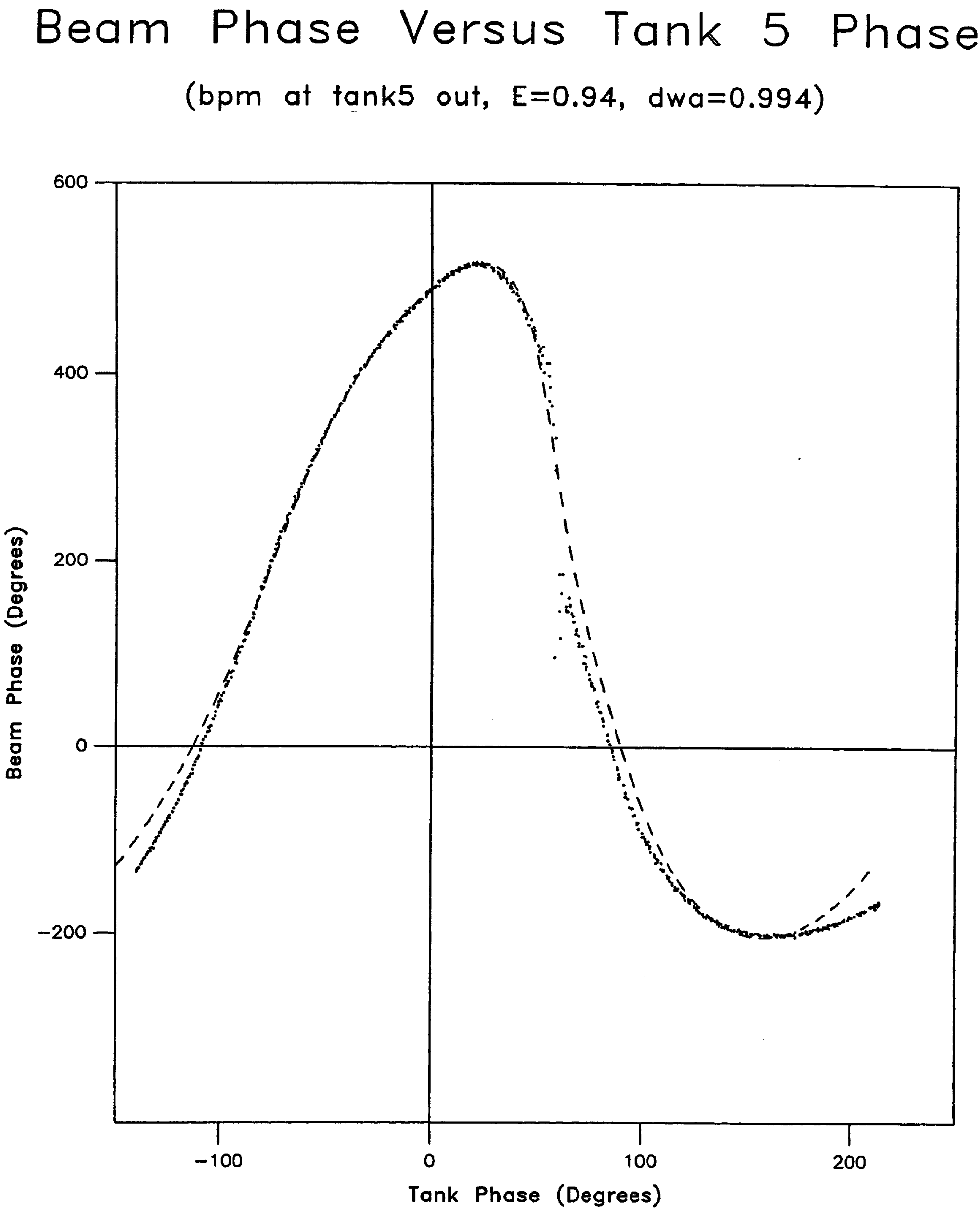

BEam Phase Versus Tank 4 Phase
(bpm at tank 4 out, E=0.98, dwa=1.0)
1200
1000
800
600
400
200
0
−200
−400
Beam Phase (Degrees)
−300
−200
−100
0
100
Tank Phase (Degrees)

Figure 1.



Beam Phase Versus Tank 5 Phase
(bpm at tank5 out, E=0.94, dwa=0.994)
600
400
200
0
−200
Beam Phase (Degrees)
−100
0
100
200
Tank Phase (Degrees)

Figure 2.

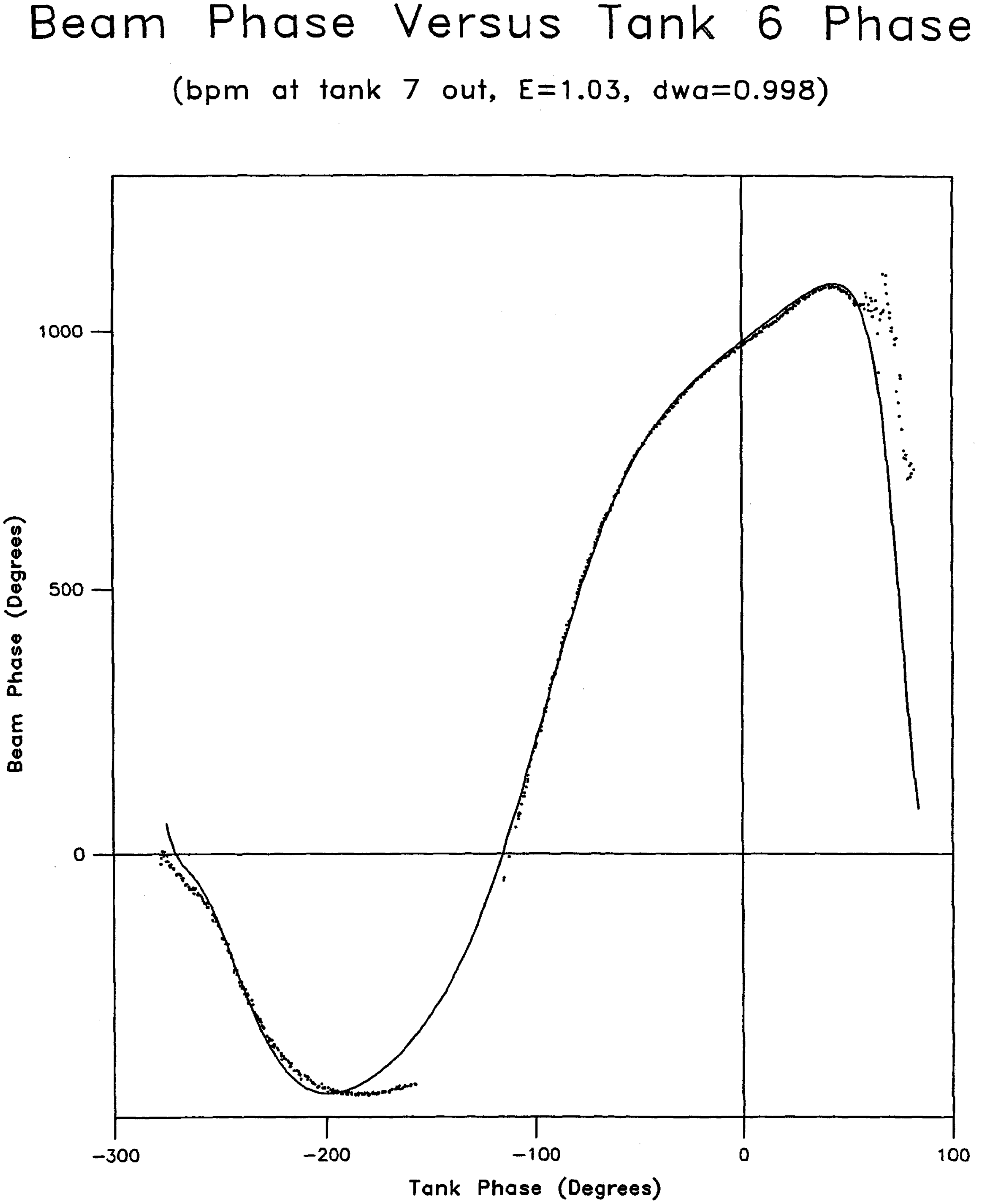
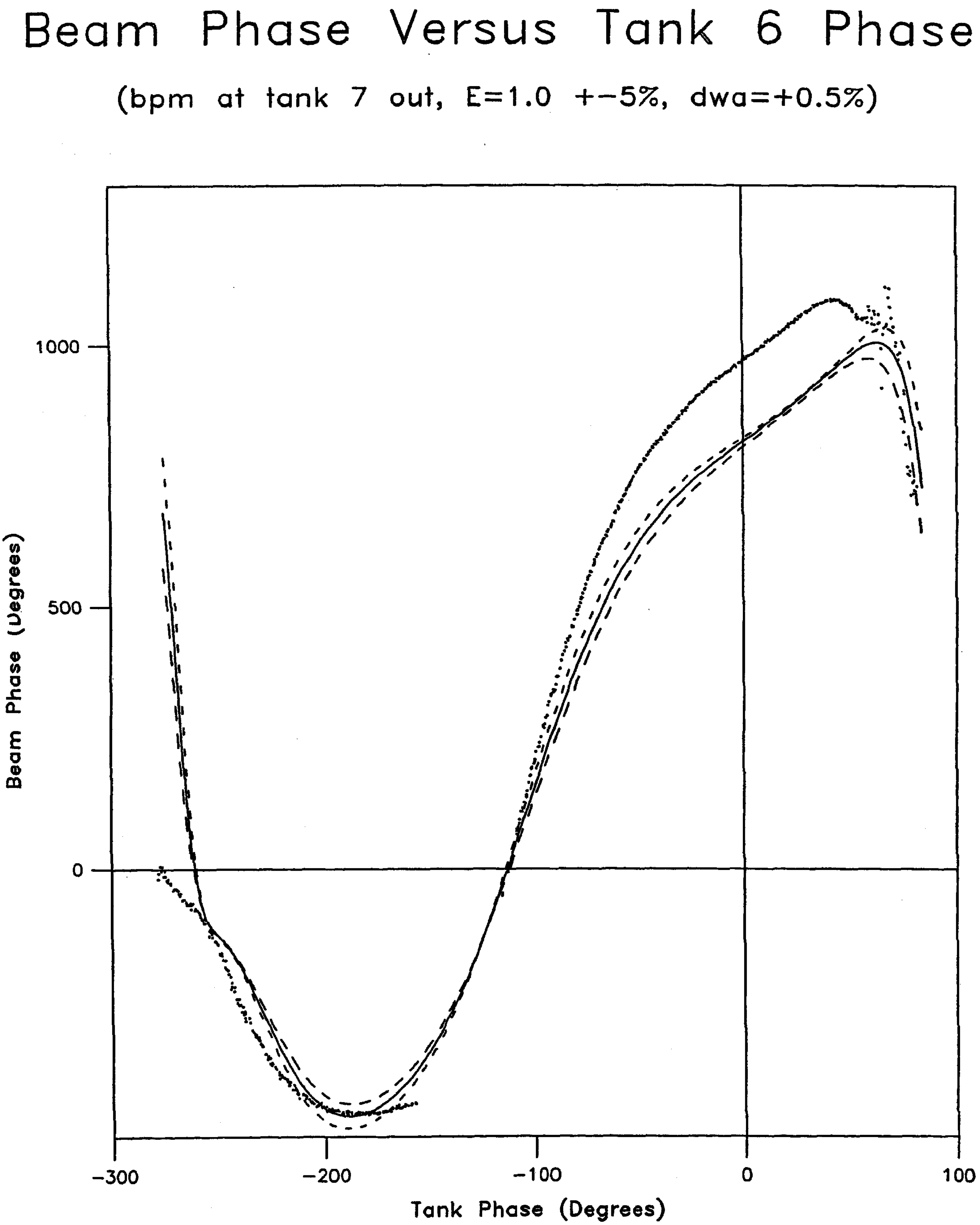

Beam Phase Versus Tank 6 Phase
(bpm at tank 7 out, E=1.03, dwa=0.998)
1000
500
0
Beam Phase (Degrees)
-300
-200
-100
0
100
Tank Phase (Degrees)

Figure 3.a



Beam Phase Versus Tank 6 Phase
(bpm at tank 7 out, E=1.0 +-5%, dwa=+0.5%)
1000
500
0
Beam Phase (Degrees)
-300
-200
-100
0
100
Tank Phase (Degrees)

Figure 3b.

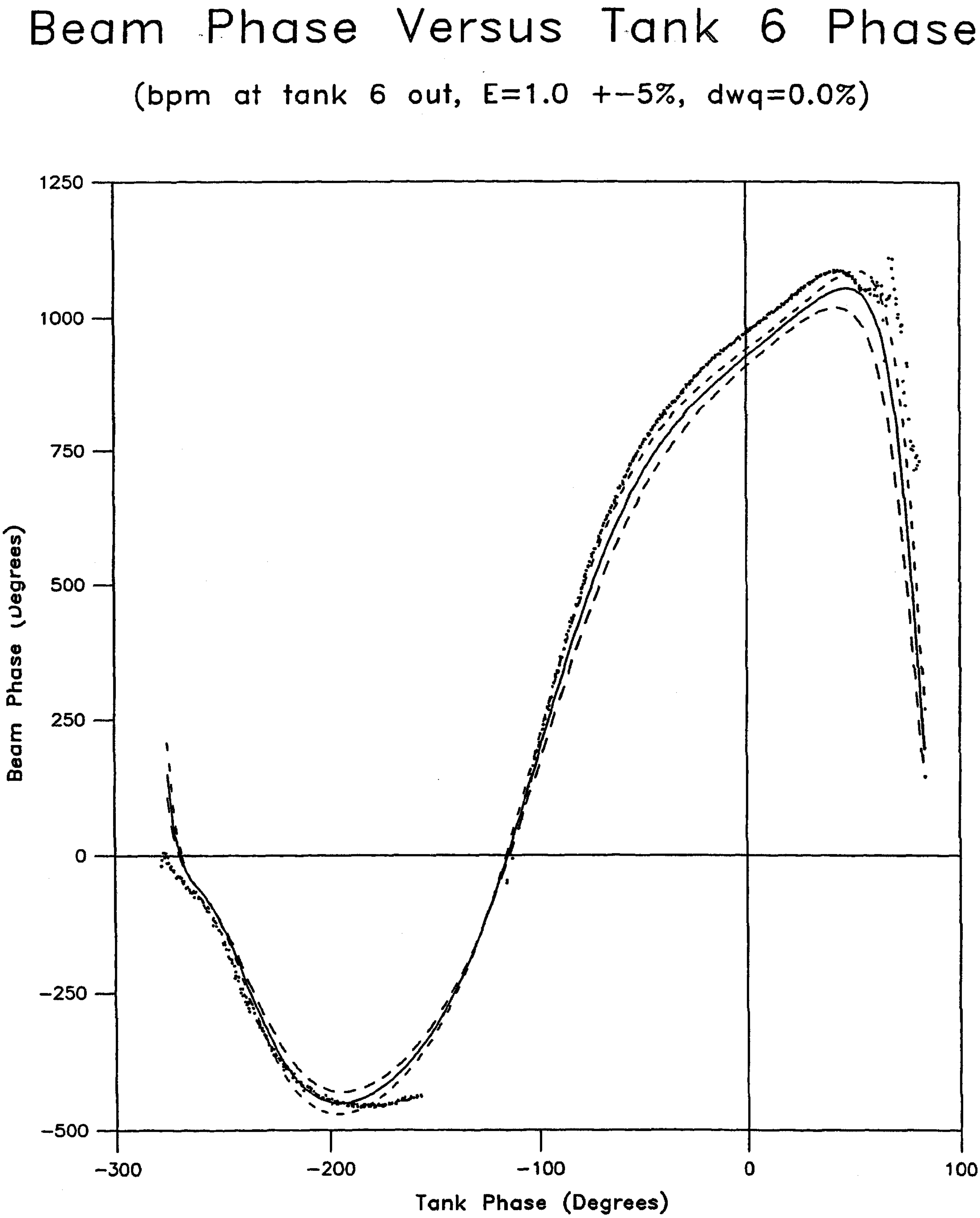

Beam Phase Versus Tank 6 Phase
(bpm at tank 6 out, E=1.0 +-5%, dwq=0.0%)
1250
1000
750
500
250
0
-250
-500
Beam Phase (Degrees)
-300
-200
-100
0
100
Tank Phase (Degrees)

Figure 3c.

Beam Phase Versus Tank 6 Phase

(bpm at tank 7 out, E=1.0 +-5%, dwa=0.995)

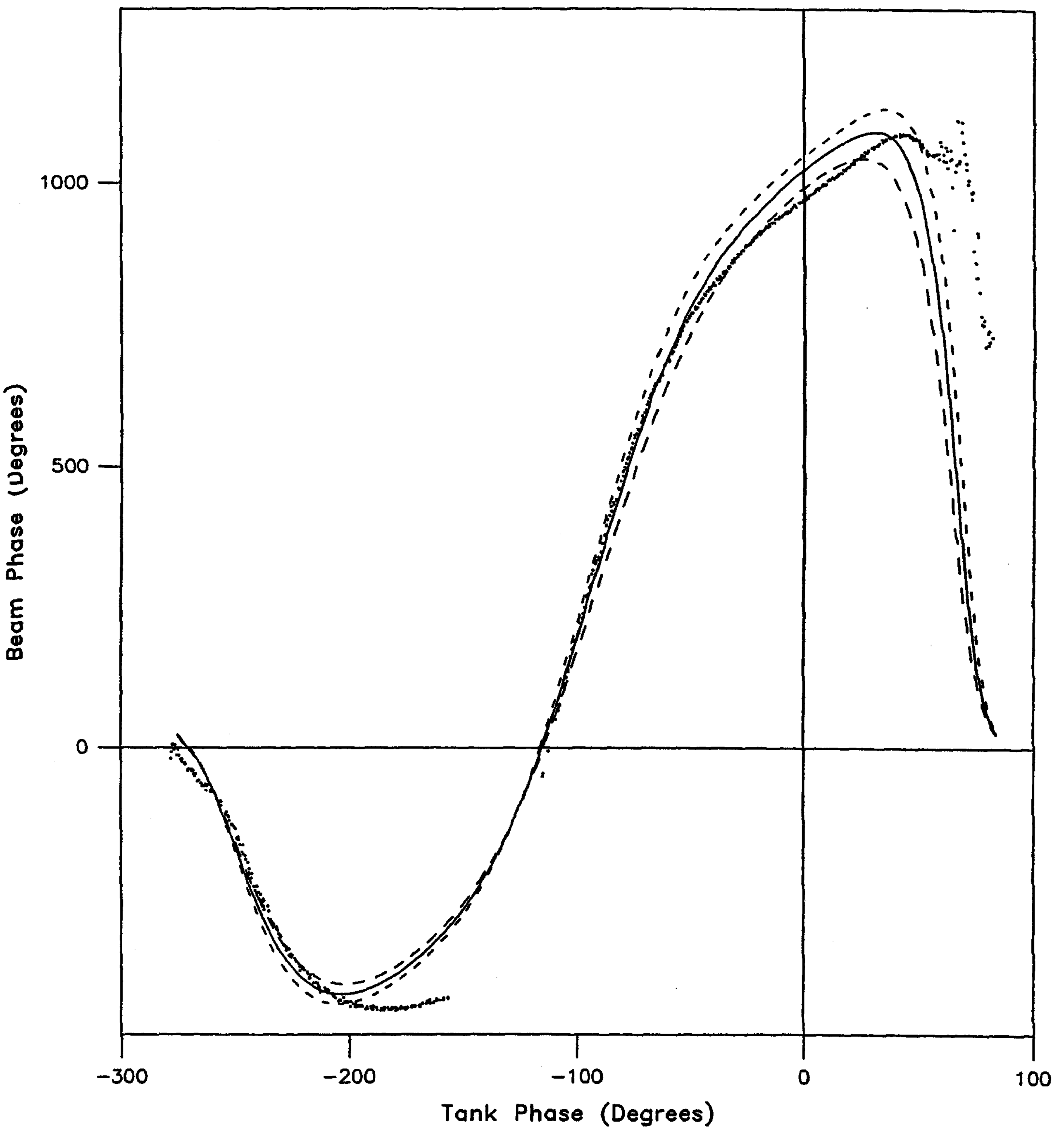


Figure 3d.

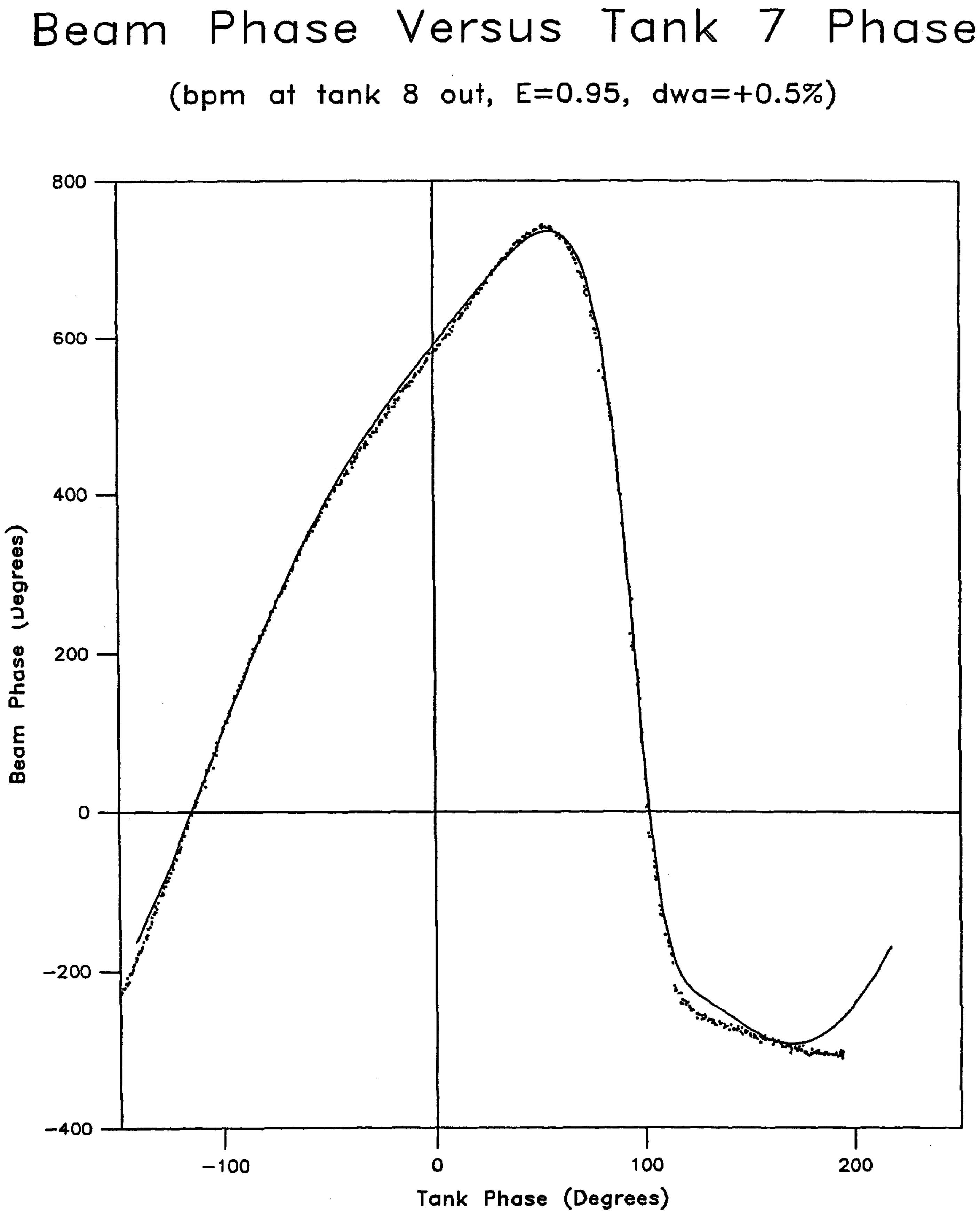
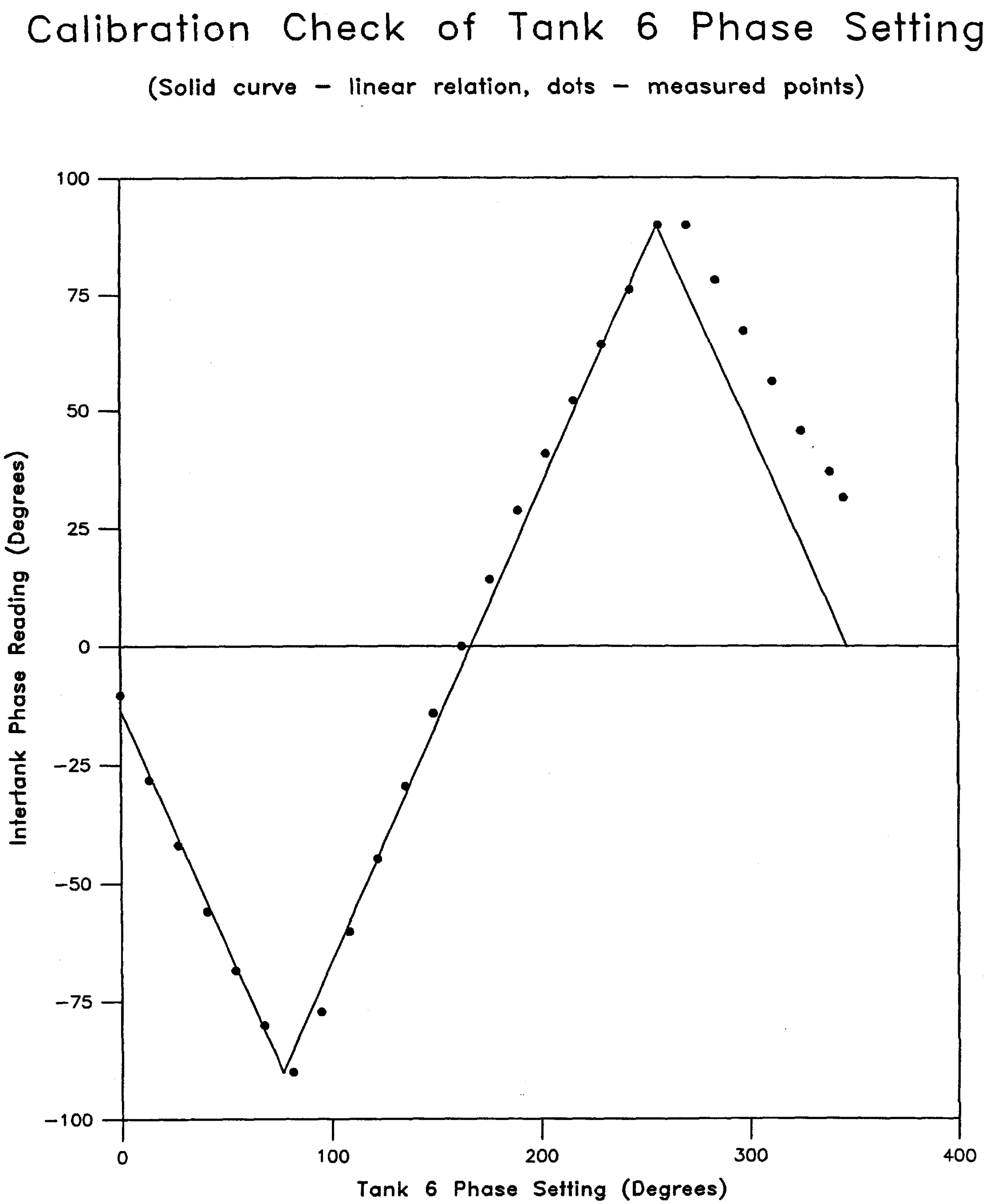

Beam Phase Versus Tank 7 Phase
(bpm at tank 8 out, E=0.95, dwa=+0.5%)
800
600
400
200
0
−200
−400
Beam Phase (Degrees)
−100
0
100
200
Tank Phase (Degrees)

Figure 4.



Calibration Check of Tank 6 Phase Setting
(Solid curve – linear relation, dots – measured points)
100
75
50
25
0
−25
−50
−75
−100
Intertank Phase Reading (Degrees)
0
100
200
300
400
Tank 6 Phase Setting (Degrees)

Figure 5.